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7100—Engineering
November 1996
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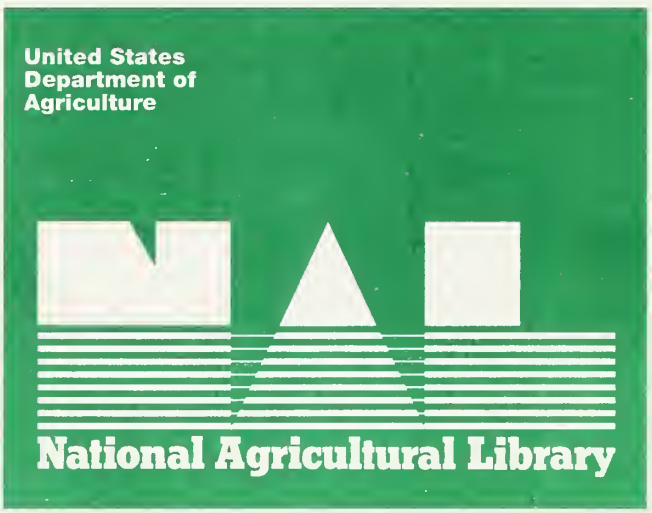
FORESTER C-2000—DEMONSTRATION PROJECT


United States
Department of
Agriculture
National Agricultural Library

FORESTER C-2000—DEMONSTRATION PROJECT

Anne Fischer, PE, Civil Engineer
Tim Pasqual, Forester C-2000 Operator
Coronado National Forest

James R. Bassel, PE, Civil Engineer
San Dimas Technology & Development Center

November 1996

CONTENTS

BACKGROUND

In the summer of 1995 the Coronado National Forest used the Forester C-2000 mobile rock crusher for eight weeks. The crusher processed 30 lane-miles of oversized material collected from shoulders, ditches, and roadway, resulting in a 4-inch road surface consisting of an estimated 30,000 cubic yards of crushed aggregate. The cost of the project was $196,811.61 (excluding transportation and technical support), with the in-place material costing $6.56 per cubic yard or $3.86 per ton.

The Forester C-2000, developed by FAHR Industries, Saint-Jacques, New Brunswick, Canada, mounts on the front of a CAT 950F front end loader (see figure 1). The crusher is powered by a CAT 3208, 255 horsepower, diesel engine and consists of eight hammers bolted through a solid steel rotor. The rotor spins in the direction that is opposite the travel of the loader. Rocks are crushed between the rotating hammers and steel anvils bolted to the top of the crusher box (see figure 2). A heavy duty chain drape hangs in front of the box keeping rocks in line for the crusher rather than the rocks being pushed out as the loader moves forward. When the rock material is crushed small enough to fit through the spaces between the hammers and the anvils, the crushed material passes out the back under a flexible belting screen into a new windrow (see figure 3).

Figure 1.
Forester C-2000 before attachment to front end loader.

Figure 2.
Crushing mechanism of Forester C-2000.

Figure 3.
Crushed material exiting Forester C-2000.

The Coronado National Forest crew included the following:

- Road Manager/Engineer (1)
- Motor Grader Operators (2)
- Loader/Crusher Operator (1)
- Water Truck Drivers (using 3 water trucks) (2)
- Crusher Assistant (1)
- Traffic Guards (2)
- Fire Crews to run pumps and fill trucks
- Technical Representative from FAHR

The primary project was a Level 3 road that ranged from 5,000 to 8,500 feet elevation. Water sources were available during the project time.

The crusher works best on cobble or boulder rock types that are angular or rounded, up to 16 inches in diameter. Bedrock can not be crushed with the Forester C-2000. The rocks were crushed down to 2-inch minus, with an occasional 3- to 4-inch rock as hammers and anvils wore down.

CRUSHING OPERATION

The crushing operation began with the motor grader ripping the road surface (see figure 4). The ripped material, along with loose rock on the shoulders and ditches, is windrowed. The size of the windrow effects the crusher's performance. An overly large windrow clogs the crusher and stalls the crusher engine, and a small windrow produces insufficient crushed material. The optimal windrow size is 5 feet wide by 1 foot high. The water truck wets the windrow for dust abatement before the crusher processes the material (see figure 5). The crusher's production rate depends on the size of windrow, the quantity and size of rock, and the road alignment. Finally, the second grader spreads the crushed material on the roadway, watering as needed.

Figure 4. Grader ripping the road surface.

MAINTENANCE OF THE CRUSHER

Routine Maintenance

Hammers last for 6 to 8 operational hours and then must be replaced (see figure 6). Under normal operating conditions this task must be done daily and takes about 30 minutes. Anvils, depending on wear, usually need to be changed once a week; this process takes about two hours. The crusher must be greased several times a day. The air filter is cleaned once a day and replaced when necessary.

Occasional Maintenance

Crusher box liner packs are rotated and replaced when they are worn out. During the two months of use, only one pack had to be rotated. Wear is dependent on the type of rock and the amount of material crushed. The hammer rotor shaft has to be hard surfaced every two to three months. The main bearings on the rotor have to be replaced every two to three months.

PROJECT RESULTS

Cost Data and Production Rates

Technical support and transportation of the equipment to/from Canada are not included in the cost of the project, but are included in the overall total cost of the project, (see table 1). The production summary is a breakdown of the time and percentages required to complete the crushing project and is included as table 2. Miscellaneous project data is included as table 3.

Figure 5. Watering windrow prior to crushing.

Figure 6. Attachment bolts and worn hammers.

Table 1. Cost data summary

Salary:	$63,512.75
Tools, diesel, supplies	9,819.64
Loader, rental	14,233.31
Other rental	6,248.69
Equipment transportation	820.00
WCF/GSA equip	15,136.19
Per diem	5,382.02
	$115,372.60
Crusher:	
Parts	$34,616.34
Rental	$46,822.67
	$81,439.01
Cost of Project	$196,811.61

Total Project Cost: $212,475.33. This price includes an additional $15,663.72 for technical support from FAHR ($7,738.72) and transportation of the Forester C-2000 to/from Canada ($7,925.00).

Table 2. Production summary.

PRODUCTION FACTORS	HOURS	PERCENTAGE
Crushing time	153.00	40.4%
Traffic delays	6.75	1.8%
Travel (Monday - Friday)	50.50	13.3%
Travel (week)	16.00	4.2%
Repair to Crusher	21.50	5.7%
Service to other equipment	25.50	6.7%
Windrow delay	21.75	5.7%
Change hammers/anvils	31.00	8.2%
Delay for water	17.00	4.5%
Mobilization	22.50	5.9%
Other downtime	13.50	3.6%
Total Project Time	**379.0 hours**	**100.0%**

Table 3. Miscellaneous Data

Total miles crushed	29.4 miles
Estimated total cubic yards	30,000 cubic yards
Estimated total tons	51,000 tons
Production rate when crushing	30,000 cubic yards/153 hours = 196 cubic yards per hour
Average miles per day	approximately 0.9 miles per day
Cost per cubic yard	$196,811.61/30,000 cubic yards = $6.56/cubic yard
Cost per ton	$196,811.61/51,000 ton = $3.86/ton

Testing

Tests were taken at three random locations during the crushing operations. A Tucson firm collected samples of material from both in front of and behind the crusher. For the 'before' sample, all rocks larger than 4 inches were discarded; the Contracting Officer's Representative (COR) noted that some discarded rocks were as large as 10 inches by 10 inches. The 'after' sample included all crushed rocks. The oversized rocks that were discarded in the 'before' sample were crushed and included in the 'after' sample (see figure 7). The samples were taken from wherever work was being done that particular day; consequently, the areas sampled were not representative of areas that contained a significant number of the larger rocks. It is highly recommended that further testing be conducted since the number of tests (three) are not enough to be truly representational of the materials found on more than 29 miles of road. These results are to be viewed as preliminary and somewhat indicative of the results one could expect. See table 4.

The following tests were performed:

- Sieve Analysis before crushing, ASTM C135 & C117
- Sieve Analysis after crushing, ASTM C135 & C117
- L.A. Abrasion, ASTM C131
- Specific Gravity and Absorption of Aggregates (Coarse), ASTM C127
- Durability Index, AASHTO T-210

Figure 7. Samples being taken for analysis.

Test sites are labeled as follows:

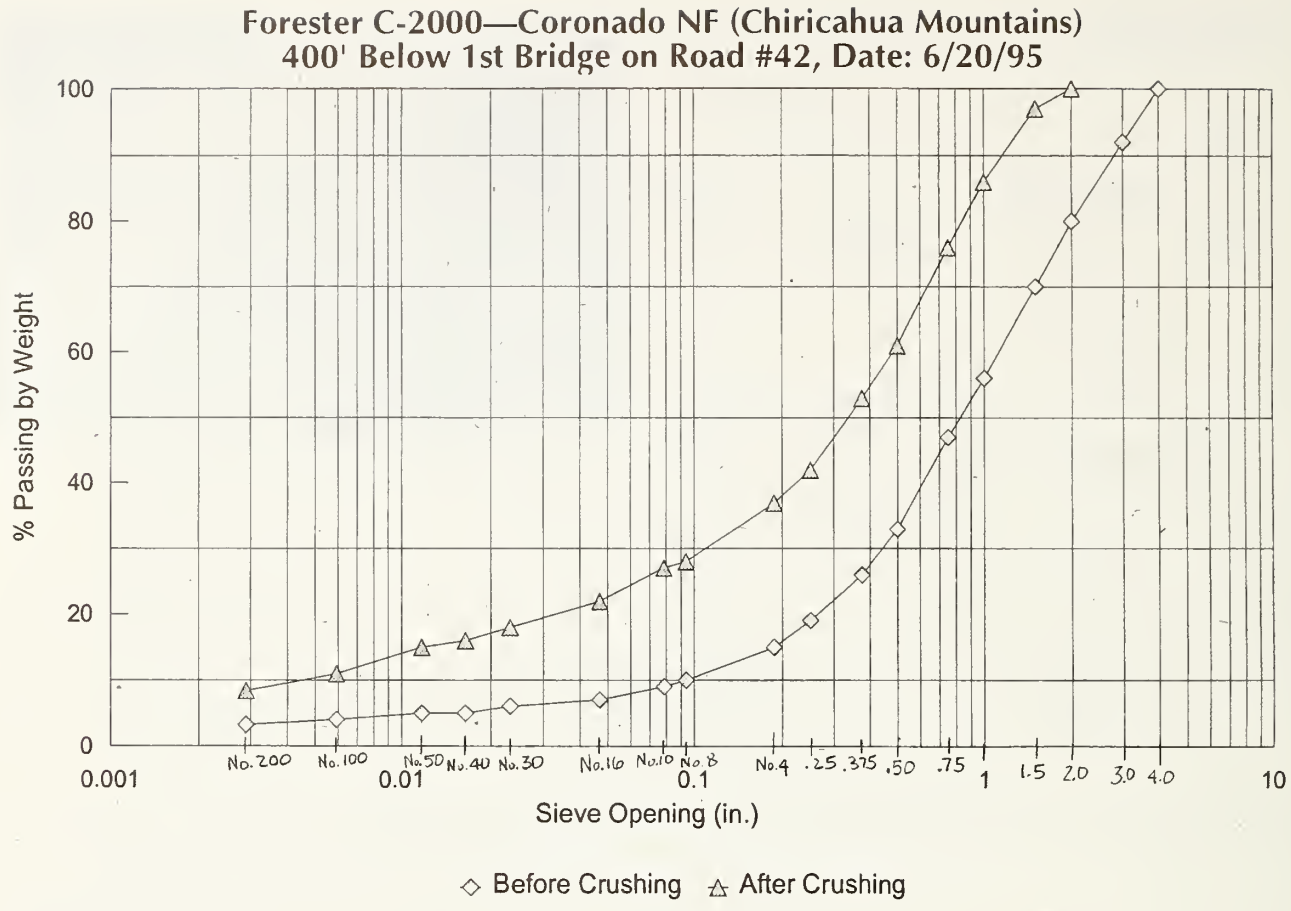
Site 1—400 foot below 1st bridge on Road #42, 6/20/95

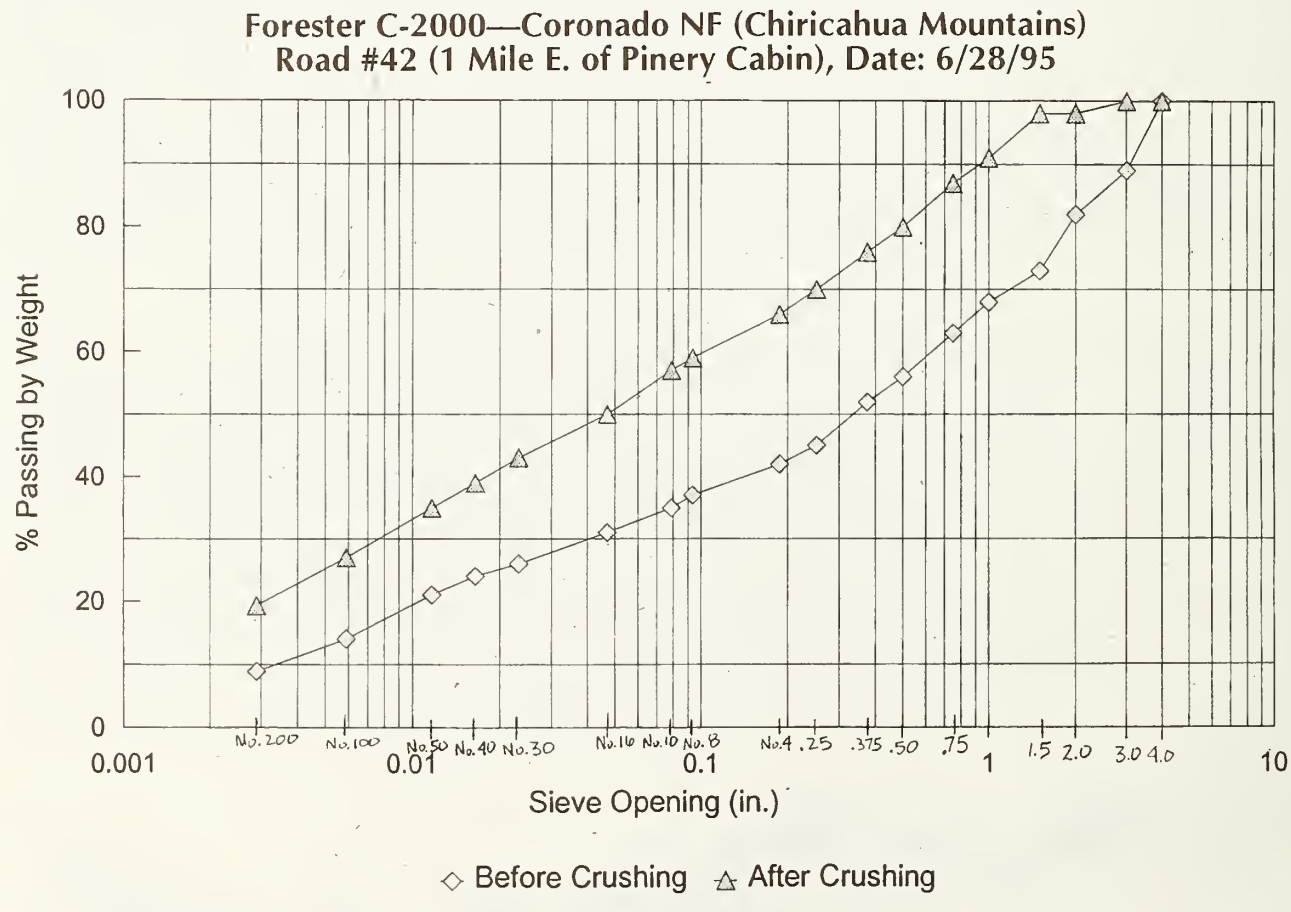
Site 2—Road #42, 1 mile East of Pinery Cabin, 6/28/95

Site 3—3 miles below Cazier Bridge, Cave Creek, Road #42, 7/1/95

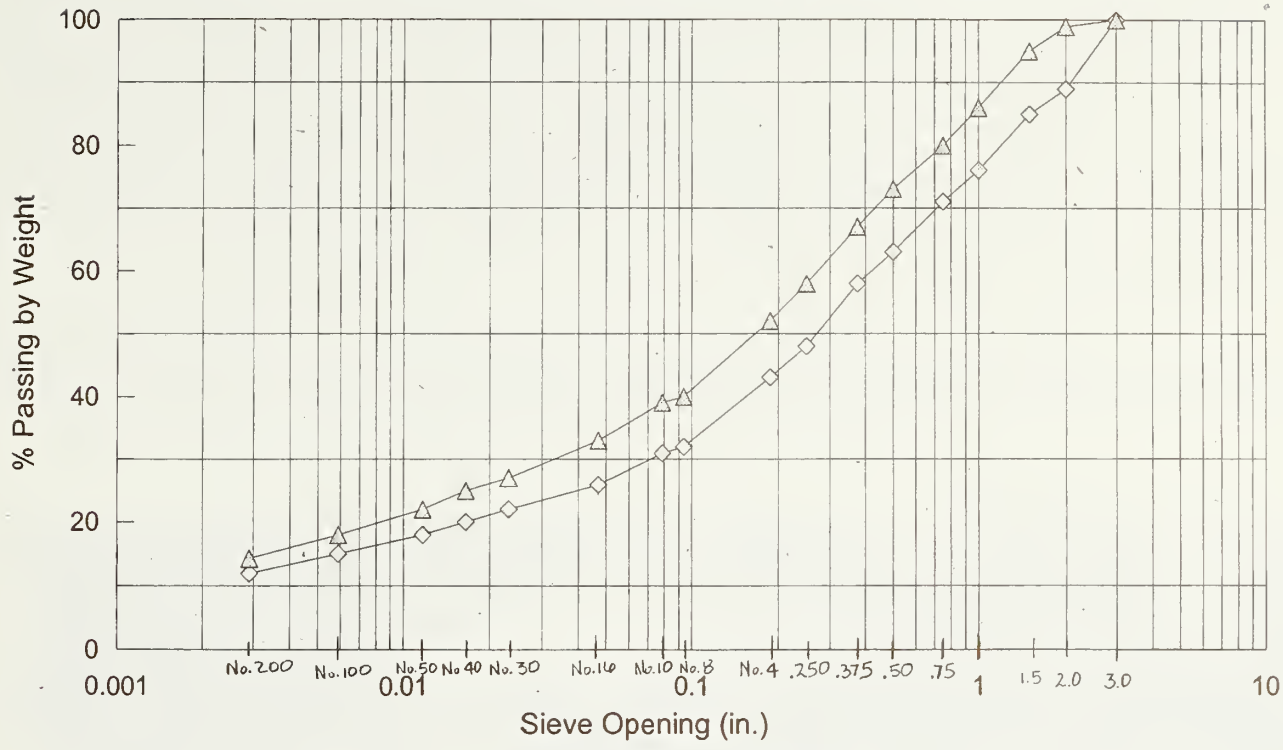
Table 4. Test results from three sites. (including graphs)

	Site 1	**Site 2**	**Site 3**
L.A. Abrasion			
Grading C			
% loss at 100 Revs	4	5	7
% loss at 500 Revs	21	25	25
Specific Gravity			
Bulk (Dry)	2.156	2.253	2.314
Bulk (SSD)	2.224	2.363	2.404
Apparent	2.312	2.532	2.542
Absorption, %	3.12	4.88	3.88
Durability Index			
Coarse	59	42	26
Fine	45	26	27


Forester C-2000—Coronado NF (Chiricahua Mountains)
400' Below 1st Bridge on Road #42, Date: 6/20/95
% Passing by Weight
100
80
60
40
20
0
0.001
0.01
0.1
1
10
No.200 No.100 No.50 No.40 No.30 No.16 No.10 No.8 No.4 .25 .375 .50 .75 1.5 2.0 3.0 4.0
Sieve Opening (in.)
◇ Before Crushing △ After Crushing

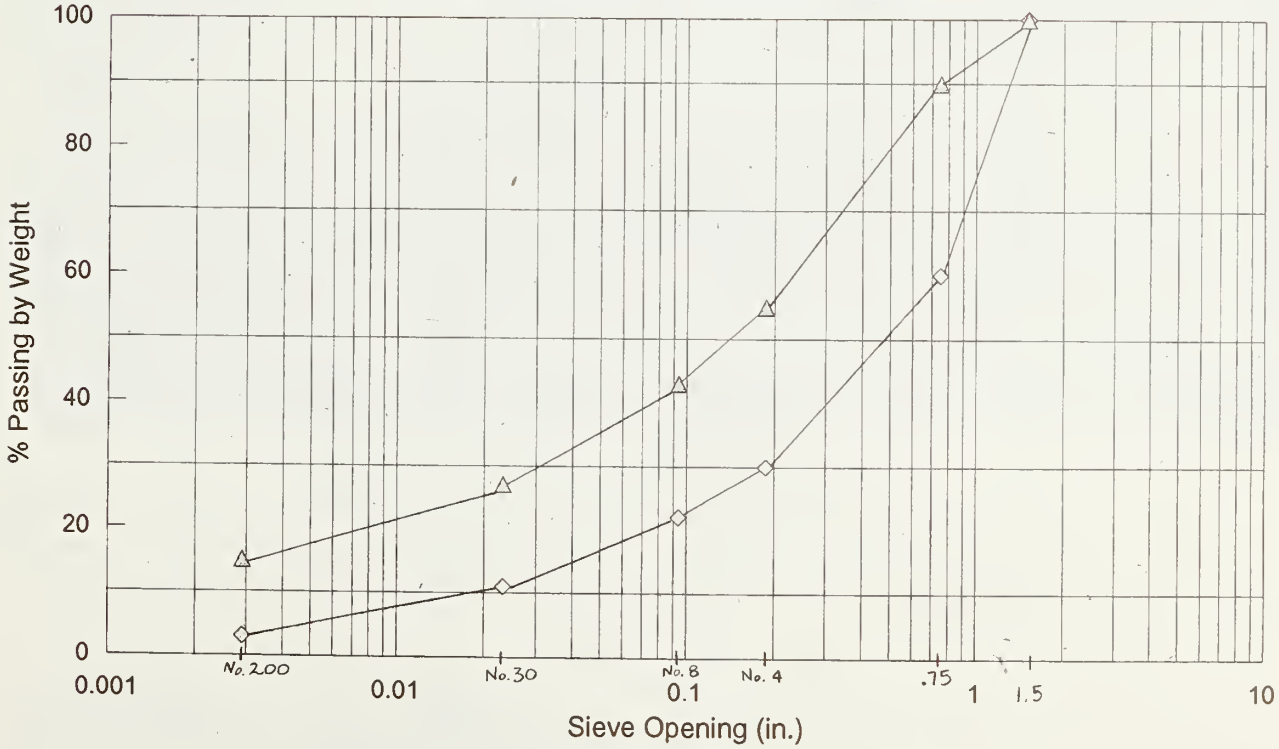

Forester C-2000—Coronado NF (Chiricahua Mountains)
Road #42 (1 Mile E. of Pinery Cabin), Date: 6/28/95
% Passing by Weight
100
80
60
40
20
0
0.001
0.01
0.1
1
10
No.200 No.100 No.50 No.40 No.30 No.16 No.10 No.8 No.4 .25 .375 .50 .75 1.5 2.0 3.0 4.0
Sieve Opening (in.)
◇ Before Crushing △ After Crushing

Forester C-2000—Coronado NF (Chiricahua Mountains)
3 Mile Below Cazier Bridge Cave Creek, Road #42, Date: 7/11/95



◇ Before Crushing △ After Crushing

USDA FOREST SERVICE
Crushed Aggregate Grading Requirements



◇ % Min. Passing △ % Max. Passing

RECOMMENDATIONS FOR IMPROVEMENT

Crusher

A few items need to be improved on the crusher in order to improve its durability. The air cleaner system needs to be expanded to include primary and secondary air cleaners and a precleaner. If dust were introduced into the system, serious damage could occur. Mr. LeBlond of FAHR recognized the potential problem as soon as he saw the extremely dry dusty conditions and plans to remedy the situation. The radiator mounting must be strengthened; it had to be welded several times during the operation. The engine mounts also need to be redesigned for greater strength. As of this date, all items discussed above have been improved.

Season Of Work

If the project had been scheduled during a wetter time of year there would have been more moisture available. The additional moisture would have increased the miles of work completed as a result of not having to rely on rental water trucks, ancillary personnel, and pumps.

Ideal Mix of Equipment

A minimum of two motor graders should be used at all times; three would be ideal. This would allow for two graders to always be in front of the crusher, ripping and windrowing the road. The third grader would handle the final grading.

At least one water truck may need to be on hand to supplement any natural moisture in the soil, even if the crusher is used during the wetter time of the year. A second truck could be used to "nurse" the first truck, thereby reducing down time for travel to a water source.

Traffic Control

If at all possible, close the road while work is in progress. During the ripping operation, the road is impassable to all but four wheel drive vehicles. Once the windrow is formed, single lane traffic is the only option, and that may not be possible if the road is narrow. Once the crushing begins, the water truck and crusher effectively block the road. Traffic delays of an hour were standard during operations on the road over the mountain.

Safety Issues

As with any heavy equipment operation, hazards exist. Ear protection must be used with the crusher; dust masks should be available; and hard hats are required. Care must be taken next to the crusher, especially when first moving into a windrow; rock fragments can fly out from the rear of the machine. Special steel braces must be fabricated to block the loader arms up when anyone is underneath the crusher performing maintenance. Vehicles should be kept away from the crusher to avoid being hit by flying rocks.

Other Uses

On the last two miles of the Cave Creek Canyon road, the crusher was used on rock and old asphalt. The pavement had been ripped and rolled back in the base a few months earlier after it was determined that it was not worth repairing. In addition, a soil stabilizer, EMC ^{2} was mixed with water and applied to the crushed aggregate. After final grading, this section of road was rolled to provided more uniform compaction.

CONCLUSION

The demonstration project using the Forester C-2000 proved to be a success considering the types of rock encountered at the test sites. (See figure 8) The 29 miles of road resurfaced with the Forester should remain in relatively good condition with only a minimal amount of additional work required.

With more than 200 threatened and endangered species in this area, development of borrow pits is extremely difficult. As a consequence, most of the surfacing material must be purchased commercially. The batch plants providing the surfacing material are far from the roads needing the material, so the resultant cost is very high. Many other roads in the area have the type of rock suitable for this kind of crusher and the roads could benefit greatly from this means of resurfacing.

The Coronado NF is in the process of purchasing a Forester C-2000. Further testing and demonstrations will be done in conjunction with the National Engineering Steering Committee and the San Dimas Technology and Development Center.

Figure 8. Forester C-2000 grinding through windrow.

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SOIL/AGGREGATE FIELD DENSITY TEST

CLIENT : *U. S. Forest Service*
Coronado National Forest
300 West Congress
Tucson, AZ 85701

JOB NO. *2945JS241*
LAB/INV NO. *F241-005*
REPORT DATE *07-18-95*
REVIEWED BY *Bob Pape*
PAGE *1* of *1*

BP

PROJECT : *CHIRICAHUA MOUNTAINS AT SUGAR PASS*
LOCATION : —
AUTHORIZED BY : *ANN FISHER* DATE : *07-14-95*
TEST LOCATIONS DESIGNATED BY : *Anne Fisher/USFS*

TEST NO.	IN-PLACE MOISTURE (%)	IN-PLACE DRY DENSITY (pcf)	IN-PLACE COMPACTION (%)	MAXIMUM DENSITY (pcf)	REQUIRED COMPACTION (%)	REQUIRED MOISTURE (%)	WITHIN SPECS?
1	*14.3*	*126.9*	*96*	*131.7*	*95*	*N/A*	*YES*

TEST NO.	TEST DATE	TEST LOCATION	ELEVATION DATUM +
1	*07/14*	*.1 Mile Above Lower Cattle Guard, 5' S. of Centerline*	*100.0*

+ DATUM: *Finished Fill Elevation = 100.0'*

TEST NO.	COMMENTS	FIELD DENSITY TEST METHOD
1	*Pavement Subbase Fill*	*ASTM D-2922/D-3017,AASHTO T-224*

MOISTURE/DENSITY RELATIONSHIP		OPTIMUM MOISTURE (%)	MAXIMUM DRY DENSITY (pcf)	TESTED PER ASTM
MATERIAL DESCRIPTION	SOURCE			
Native	*Pavement Subbase Fill*	*11.2*	*124.2*	*T-272-A*

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Note - These tests are not part of a program of continuous monitoring of compaction operations. Results apply to the actual locations tested only.

APPENDICES/LAB RESULTS

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SOIL/AGGREGATE FIELD DENSITY TEST

CLIENT : *U. S. Forest Service*
Coronado National Forest
300 West Congress
Tucson, AZ 85701

JOB NO: *2945JS241*
LAB/INV NO. *F241-006*
REPORT DATE *08-03-95*
REVIEWED BY *Bob Pape*
PAGE *1* of *1*

BP

PROJECT : *CHIRICAHUA MOUNTAINS AT SUGAR PASS*
LOCATION : –
AUTHORIZED BY : *ANN FISHER* DATE : *07-20-95*
TEST LOCATIONS DESIGNATED BY : *Anne Fisher/USFS*

TEST NO.	IN-PLACE MOISTURE (%)	IN-PLACE DRY DENSITY (pcf)	IN-PLACE COMPACTION (%)	MAXIMUM DENSITY (pcf)	REQUIRED COMPACTION (%)	REQUIRED MOISTURE (%)	WITHIN SPECS?
1	13.8	118.5	97	121.7	95	N/A	YES
2	7.3	121.9	98	123.8	95	N/A	YES
3	8.6	116.7	99	117.7	95	N/A	YES
4	8.0	125.2	100+	119.9	95	N/A	YES

TEST NO.	TEST DATE	TEST LOCATION	ELEVATION DATUM+
1	07/20	Below Paul Hirt	100.0
2	07/20	White Ribbon by Forest Boundary, Paul Hirt Location	100.0
3	07/20	By Well	100.0
4	07/20	Orchard Location	100.0

+DATUM: *Finished Fill Elevation = 100.0'*

TEST NO.	COMMENTS	FIELD DENSITY TEST METHOD
1	Roadway Subbase Fill	ASTM D-2922/D-3017,AASHTO T-224
2	Roadway Subbase Fill	ASTM D-2922/D-3017,AASHTO T-224
3	Roadway Subbase Fill	ASTM D-2922/D-3017,AASHTO T-224
4	Roadway Subbase Fill	ASTM D-2922/D-3017,AASHTO T-224

MOISTURE/DENSITY RELATIONSHIP				
MATERIAL DESCRIPTION	SOURCE	OPTIMUM MOISTURE (%)	MAXIMUM DRY DENSITY (pcf)	TESTED PER ASTM
Native	Paul Hirt Location	10.5	125.7	D-698-C
Native	Orchard Location	11.9	117.7	D-698-C

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Note - These tests are not part of a program of continuous monitoring of compaction operations. Results apply to the actual locations tested only.

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LABORATORY REPORT

PHYSICAL PROPERTIES OF AGGREGATES

Client: US FOREST SERVICE
300 WEST CONGRESS
TUCSON AZ 85701

Job No. 2945JS241
Lab/Inv. No. F241-001
Report Date: 06/20/95

Project: CHIRICAHUA MOUNTAINS AT SUGAR PASS
Location:
Material: Aggregate (After Crushing) Sampled By: WT/Thompson Date 06/20/95
Source: 400' Below 1st Bridge (Upper) on Submitted By: WT/Thompson Date 06/20/95
Road #42 (Pinery Canyon) Authorized By: Anne Fisher Date 06/20/95

SIEVE ANALYSIS, ASTM C136 & C117

Sieve Size	% Passing Accumulative	Specification (As Required)
4"		
3"		
2"	100	
1-1/2"	97	
1"	86	
3/4"	76	
1/2"	61	
3/8"	53	
1/4"	42	
No. 4	37	
8	28	
10	27	
16	22	
30	18	
40	16	
50	15	
100	11	
200	8.4	

Specific Gravity & Absorption of Aggregates (Coarse)	ASTM C127
Bulk (Dry)	2.156
Bulk (SSD)	2.224
Apparent	2.312
Absorption, %	3.12

L.A. Abrasion, ASTM C131,

Grading C	
% Loss at 100 Revs.	4
% Loss at 500 Revs.	21

Durability Index (AASHTO T-210)	
Coarse	59
Fine	45

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LABORATORY REPORT

PHYSICAL PROPERTIES OF AGGREGATES

Client: US FOREST SERVICE
300 WEST CONGRESS
TUCSON AZ 85701

Job No. 2945JS241
Lab/Inv. No. F241-001
Report Date: 06/20/95

Project: CHIRICAHUA MOUNTAINS AT SUGAR PASS
Location:
Material: Aggregate (Before Crushing) Sampled By: WT/Thompson Date 06/20/95
Source: 400' Below 1st Bridge (Upper) on Submitted By: WT/Thompson Date 06/20/95
Road #42 (Pinery Canyon) Authorized By: Anne Fisher Date 06/20/95

SIEVE ANALYSIS, ASTM C136 & C117

Sieve Size	% Passing Accumulative	Specification (As Required)
4"	100	
3"	92	
2"	80	
1-1/2"	70	
1"	56	
3/4"	47	
1/2"	33	
3/8"	26	
1/4"	19	
No. 4	15	
8	10	
10	9	
16	7	
30	6	
40	5	
50	5	
100	4	
200	3.2	

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LABORATORY REPORT

PHYSICAL PROPERTIES OF AGGREGATES

Client: US FOREST SERVICE
300 WEST CONGRESS
TUCSON AZ 85701

Job No. 2945JS241
Lab/Inv. No. F241-002
Report Date: 06/28/95

Project: CHIRICAHUA MOUNTAINS AT SUGAR PASS
Location:
Material: Aggregate (After Crushing) Sampled By: WT/Thompson Date 06/28/95
Source: Road #42 (1 Mile E. of Pinery Cabin) Submitted By: WT/Thompson Date 06/28/95
Authorized By: Anne Fisher Date 06/14/95

SIEVE ANALYSIS, ASTM C136 & C117

Sieve Size	% Passing Accumulative	Specification (As Required)
4"		
3"	100	
2"	98	
1-1/2"	98	
1"	91	
3/4"	87	
1/2"	80	
3/8"	76	
1/4"	70	
No. 4	66	
8	59	
10	57	
16	50	
30	43	
40	39	
50	35	
100	27	
200	19.3	

Specific Gravity & Absorption of Aggregates (Coarse)	ASTM C127
Bulk (Dry)	2.253
Bulk (SSD)	2.363
Apparent	2.532
Absorption, %	4.88

L.A. Abrasion, ASTM C131, Grading C	
% Loss at 100 Revs.	5
% Loss at 500 Revs.	25

Durability Index (AASHTO T-210)	
Coarse	42
Fine	26

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LABORATORY REPORT

PHYSICAL PROPERTIES OF AGGREGATES

Client: US FOREST SERVICE
300 WEST CONGRESS
TUCSON AZ 85701

Job No. 2945JS241
Lab/Inv. No. F241-002
Report Date: 06/28/95

Project: CHIRICAHUA MOUNTAINS AT SUGAR PASS
Location:
Material: Aggregate (Before Crushing) Sampled By: WT/Thompson Date 06/28/95
Source: Road #42 (1 Mile E. of Pinery Cabin) Submitted By: WT/Thompson Date 06/28/95
Authorized By: Anne Fisher Date 06/14/95

SIEVE ANALYSIS, ASTM C136 & C117

Sieve Size	% Passing Accumulative	Specification (As Required)
4"	100	
3"	89	
2"	82	
1-1/2"	73	
1"	68	
3/4"	63	
1/2"	56	
3/8"	52	
1/4"	45	
No. 4	42	
8	37	
10	35	
16	31	
30	26	
40	24	
50	21	
100	14	
200	8.9	

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LABORATORY REPORT

PHYSICAL PROPERTIES OF AGGREGATES

Client: US FOREST SERVICE
300 WEST CONGRESS
TUCSON AZ 85701

Job No. 2945JS241
Lab/Inv. No. F241-004
Report Date: 07/11/95

Project: CHIRICAHUA MOUNTAINS AT SUGAR PASS
Location:
Material: Aggregate (After Crushing) Sampled By: WT/Thompson Date 07/11/95
Source: .3 Mile Below Cazier Bridge - Submitted By: WT/Thompson Date 07/11/95
Cave Creek - Road #42 Authorized By: Anne Fisher Date 07/10/95

SIEVE ANALYSIS, ASTM C136 & C117

Sieve Size	% Passing Accumulative	Specification (As Required)
4"		
3"	100	
2"	99	
1-1/2"	95	
1"	86	
3/4"	80	
1/2"	73	
3/8"	67	
1/4"	58	
No. 4	52	
8	40	
10	39	
16	33	
30	27	
40	25	
50	22	
100	18	
200	14.3	

Specific Gravity & Absorption of Aggregates (Coarse)	ASTM C127
Bulk (Dry)	2.314
Bulk (SSD)	2.404
Apparent	2.542
Absorption, %	3.88

L.A. Abrasion, ASTM C131, Grading C	
% Loss at 100 Revs.	7
% Loss at 500 Revs.	25

Durability Index (AASHTO T-210)	
Coarse	26
Fine	27

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Tucson, Arizona 85713-5435
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LABORATORY REPORT

PHYSICAL PROPERTIES OF AGGREGATES

Client: US FOREST SERVICE
300 WEST CONGRESS
TUCSON AZ 85701

Job No. 2945JS241
Lab/Inv. No. F241-004
Report Date: 07/11/95

Project: CHIRICAHUA MOUNTAINS AT SUGAR PASS

Location:

Material: Aggregate (Before Crushing) Sampled By: WT/Thompson Date 07/11/95

Source: .3 Mile Below Cazier Bridge - Submitted By: WT/Thompson Date 07/11/95
Cave Creek - Road #42 Authorized By: Anne Fisher Date 07/10/95

SIEVE ANALYSIS, ASTM C136 & C117

Sieve. Size	% Passing Accumulative	Specification (As Required)
4"		
3"	100	
2"	89	
1-1/2"	85	
1"	76	
3/4"	71	
1/2"	63	
3/8"	58	
1/4"	48	
No. 4	43	
8	32	
10	31	
16	26	
30	22	
40	20	
50	18	
100	15	
200	11.9	

Copies: CLIENT (2)

REVIEWED BY Robert R Pope
(Signed Copy on File)

GPO 583-092/31018